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The Implementation of Highways Tracing Physical Model – "Flexible Bracelet"

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Abstract

The perspective direction of computer-aided designing of road is optimization algorithms development. Optimization problems solutions can improve the quality of roads projects. Analysis of optimization methods in computer-aided road design system has been shown. These problems solving through the method of flexible bracelet implementation had been suggested. In the article the concept of the geometric implementation of the flexible bracelet method as a method of computer-aided highways designing has been considered. It is advisable to use a rectangle as the flexible bracelet link at this stage of this method development.

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Keywords: computer-aided road design system (CARDS); optimization; track; horizontal alignment of track; vertical alignment of track; manual designing of highways; driver; methods of linear (non-linear) programming; the method of flexible bracelet (MFB); tracing of highways.

1. Introduction

Computer-aided road design system (CARDS) can improve quality of design decisions significantly. The basis of the computer technology software component is the use of looping. The application of looping allows to solve optimization problems. Exactly the optimization problems solving allows to achieve quality design solutions. That is why specialists of CARDS worked in this direction since the 60s of the last century (Федотов 1986). However, the low level of computers restrained the pace of development this trend.

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Now, when computer technology hardware component has made a breakthrough in all characteristics, direction of solving optimization problems is not a priority. This fact proves the analysis of modern CARDS. For example, in Greek CARDS – Anadelta Tessera (http://www.anadelta.com link is valid for 10.02.2015) all the attention of developers is focused on the design decisions visualization, but the tracing process, the design of longitudinal profile, is no different from manually technology.

We do not see optimization algorithms in the system Advanced Road Design V14 (http://www.advance-droaddesign.com.au/link is valid for 10.02.2015). We can see more technical opportunities for optimization but less optimization solutions.

2. Analysis of optimization methods in CARDS

Soviet specialists used optimization algorithms in vertical alignment (Федотов 1986). For designing of road longitudinal profile optimization method of boundary (Filshtain 1967) and iterations gradient projection method (Khavkin 1965) had been developed.

Abdullah E. Akay had considered the evolution of computer-aided road design systems (Akay 2005). He highlights 8 computer-aided road design systems:

system I: Parker N. A. (1977) had used a approach to determine the horizontal and vertical alignment that minimized construction costs;

system II: Trypia M., (1979) had developed a model to minimize the total construction cost;

system III: Mayer R. and Stark R (1981) had developed a linear programming model for minimizing the cost of the earthmoving activities;

system IV: Easa S. M. (1988) had developed a model to minimize the cost of earthwork by including the borrow costs;

system V: Goh C. J. (1988) had included transport costs into computer-aided road design and had developed dynamic programming model (Version-a) and state parameterization (Version-b) model;

system VI: Douglas R. A. and B. S. Henderson, (1987) had developed a computer dynamic programming model for forest road location problems;

system VII: Ichihara K. et al., (1996) had developed a model to locate the vertical alignment of a forest road with minimum construction costs;

system VIII: Akay, A. E., (2003) developed 3-D forest road alignment model to optimally locate the road alignment by minimizing different parameters.

Akay allocated 9 optimization criteria (see Table 1).

The most complete is Akay system (Akay 2006).

Table 1. Capabilities of the systems based on the specified criteria (Akay 2005).

Systems	Criteria								
	Solution time	Input time	Vertical alignment	Optimal earthwork	Construction costs	Maintenance costs	Transport costs	Environmental costs	Driver safety
I	•	•	•	•	•				
II		•	•	•					
III	•		•	•					
IV	•		•	•					
Va	•	•	•		•		•		•
Vb	•	•	•		•		•		•
VI	•	•	•		•				
VII	•	•	•		•				
VIII	•	•	•	•	•	•	•	•	•

The above systems have a significant disadvantage: systems for use on computers in 1965 and even 2005 have been outdated for modern computer technology.

They can have topical approach but not actual implementation. An engineer must use a system, that have topical approach aimed at actual implementation.

The analytical forecasting CARDS development shows tandem theory and computer capabilities (Мусиенко 2012).

3. The main approaches for CARDS

The main approaches for CARDS are tangential tracing and tracing by method of flexible ruler. The first approach involves tracing by straight sections with circular curves. Also this approach is used for manual highways design technology, because it is realized through simple calculations. In this approach, straight sections have priority, so in general they dominate; finally it negatively affects on road safety.

In the past tracing by method of flexible ruler realized with flexible ruler respectively. For computer-aided designing of this process specialists use different functional dependencies as the curves which simulate flexible ruler. For example, CARDS CREDO's developers implemented the method of splines tracing through the points (http://www.credo-dialogue.ru link is valid for 10.02.2015) (Fig. 1).

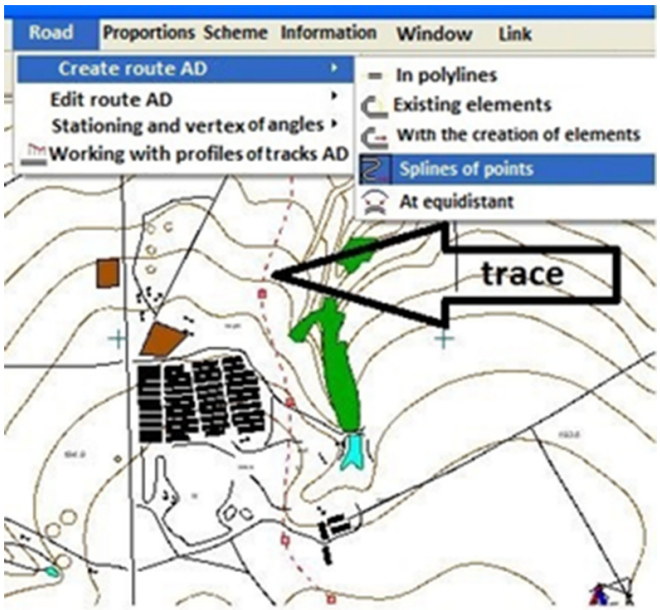

Fig. 1. An example of the method of splines tracing through the points in CARDS CREDO.

4. Physical models of tracks

In modern CARDS the physical model of the proposed flexible curves and tracks – is a «rubber thread» that has many degrees of freedom.

Many degrees of freedom determine the complexity of optimization algorithms. The number of iterations for solving optimization problems is extremely limited, because digital model of the project is a very complex spatial 3D model (even at the present level of computer technology development). One way out of this situation is to reduce the degrees of freedom of the track without reducing its functional fitness. The process of reducing the degrees of freedom as the road system in the language of systems theory called the process of reducing the complexity of the system (Гаврилов et al. 2004).

One of the system complexity determining concepts is the information-theoretic concept that links system complexity and system entropy. In this concept W. Ashby suggested to use variety as measure of the complexity that estimated by number of possible states of the system *n*.

L. Hartley proposed to use the logarithmic scale in order to estimate the system complexity (Гаврилов et al. 2004):

$$H_m = \log n, \tag{1}$$

where, H_m – a measure of complexity (the maximum entropy of the system).

The physical model – "flexible bracelet" provide greater track flexibility at lower maximum entropy compared to the physical model "rubber thread" (Musiienko 2013). Space curve in this model is also flexible, but it has some limitations, and accordingly maximum entropy in this model is less. Extra flexibility present in the "rubber thread" model excessive flexibility. Extra flexibility makes implementation of optimization algorithms difficult.

5. Implementation of the physical model – "flexible bracelet"

The method of flexible bracelet (MGB) had been proposed as implementation of highways tracing physical model – "flexible bracelet" (Угненко, Мусиенко 2012). The essence of this method is as follows: there is some initial indivisible element, which can have a different geometric shape in the plane and in space. It is connected to another element via linkage. Linkage can be both rigid and flexible. The track of road is the curve that approximates the geometric centers of the initial indivisible elements. It is advisable to start implementation of this method using rectangle as an initial indivisible element, because rectangle is the simplest possible geometric shapes. Linkage must be rigid as the simplest case also (Fig. 2).

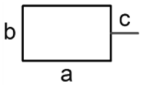

Fig. 2. The structural element of a track – rectangle: a – length of the element; b – width of the element; c – length of the linkage.

The straight line is elementary case of tracing between points A and B (Fig. 3).

Length of the track is determined by the formula:

$$L_{AB} = a \cdot n_1 + c \cdot n_2 + \Delta_a(\Delta_c), \tag{2}$$

where n_1 – the number of whole units belonging to the segment AB, m; n_2 – the number of whole linkage belonging to the segment AB; Δ_a – the remainder of element length, m; Δ_s – the remainder of linkage length, m.

The flexible bracelet circle inscribing is the more complicated case of MGB tracing (Fig. 4).

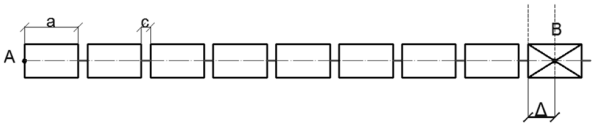

Fig. 3. Straight tracing.

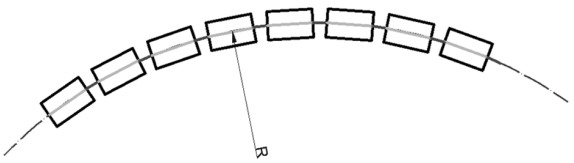

Fig. 4. The flexible bracelet circle inscribing.

We have two cases for flexible bracelet circle inscribing: when elements do not touch each other on the inner edge (Fig. 4) and when they contact (limit position of the links). Limit position of elements is determined by their geometry (Fig. 5).

Curvature of a highway track in MFB can be determined by two factors: MFB geometry constraints (FBC) and situation (relief) constraints (SRC).

Curvature of a highway track according to FBC is depended on link forms in plane and in space, link geometry, type of linkage (flexible, rigid), length of linkage, changes in these parameters along the track.
Curvature of a highway track according to SRC is depended on highways designing norms (minimum or recommended radiuses, minimum or recommended slope, parameters of clothoid etc.)
The circle inscribing of flexible bracelet when elements contact has some radius. The problem of determining this radius is an important geometrical problem of sizes assignment for elements and linkage (Fig. 6).

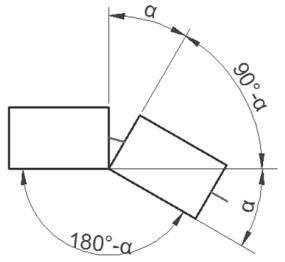

Fig. 5. Limit position of elements.

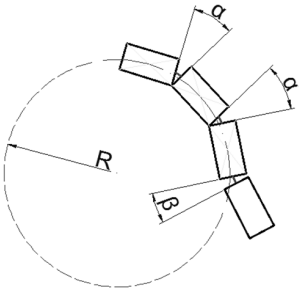

Fig. 6. The track radius at limit position of elements.

This radius of the circle is defined by formula Beluali (Мусиенко, Булуали Алале 2012):

$$R = \left(\frac{\sqrt{\frac{a^2}{2} \cdot \left[ver \sin(180 - \alpha) \right]}}{2 \cdot \sin\left(\frac{\alpha}{2} \right)} \right) + \left(\frac{b}{2} \right), \tag{3}$$

where a – link length, m; b – link width, m; α – angle between two link, degrees.

Angle α is calculated by the formula:

$$\alpha = 2 \cdot \arcsin\left(\frac{c}{b} \right). \tag{4}$$

6. Conclusions

The optimization algorithms development is topical areas of CARDS. MFB had been proposed in order to facilitate optimization solving problem. At this stage of the MGB development the problem of determining radius of circle (inscribing of flexible bracelet when elements contact) has been solved. The next step is to define the basic principles of optimizing of track layout in plane.

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